UNDERSTANDING AND DETERMINING THE COST OF LONG TERM MAINTENANCE AND RESILIENCE OF WSD

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ABSTRACT

Unless carefully managed, continual growth pressures on New Zealand's cities and urban-rural fringes will lead to increasing effects from stormwater discharges on our coastal and freshwater receiving environments. Water sensitive design (or green infrastructure) provides developers and councils with an opportunity to better protect the receiving environment from these effects through the concept of 'designing with nature'. This is achieved through the acknowledgement, preservation and use of the inherent natural landform and hydrology, and the integration of stormwater design with landscape and architectural elements.

The stormwater industry in New Zealand is coming to the realisation that piped systems provide an on-going asset management liability with regard to operation, maintenance and renewal. These systems are also difficult to monitor, relatively hard to access, prone to blockage and structural failure, and there is an on-going risk of underground systems receiving wastewater cross connections. On the other hand research and recent experience in New Zealand and overseas has shown that green infrastructure solutions are likely to be more robust and resilient than traditional solutions, both in terms of coping with long term changes in climatic conditions and short term chronic events such as earthquakes, in addition to reduced blockage risks. Research and experience has also shown that green infrastructure systems are also more economical to construct, but maintenance costs of diffuse green infrastructure (such as rain gardens and swales) can be more expensive than traditional approaches.

This paper provides a stock take of our current understanding of costs of WSD, and explores the issues of resilience and long term cost effectiveness of green infrastructure stormwater management solutions.

KEYWORDS

Water Sensitive Design, green infrastructure, resilience, maintenance costs

PRESENTER PROFILE

Sue Ira is the Director of Koru Environmental Consultants Limited. She is an environmental scientist with 17 years' experience working in stormwater management.

Sue has extensive experience in catchment management planning, peer review and stakeholder consultation. She was the primary developer of the $COST_{NZ}$ Model and has developed a catchment-scale stormwater LCC model for NIWA and the Cawthron Institute.

Andres Roa is the Founding Director of AR Civil Consulting Ltd (now AR & Associates Ltd). Andrés has approximately 20 years professional experience with projects for both the private and public sectors throughout New Zealand and overseas. Andrés' experience covers a wide range of fields and lately has focused on integrated engineering design and WSD.

1 INTRODUCTION

Councils across New Zealand face a number of significant stormwater problems arising from the growth, development and redevelopment of urban centres. Unless carefully managed, continual growth pressures on New Zealand's cities and urban-rural fringes will lead to increasing effects from stormwater discharges on our coastal and freshwater receiving environments. Water sensitive design (WSD) (or green infrastructure) provides developers and councils with an opportunity to better protect the receiving environment from these effects through the concept of 'designing with nature'. This is achieved through the acknowledgement, preservation and use of the inherent natural landform and hydrology, and the integration of stormwater design with landscape and architectural elements. There has been much research undertaken to document the environmental protection and social benefits of WSD. However, a key impediment to its implementation is the perception that WSD costs more than conventional stormwater management approaches in both implementation and operation.

Costing models, such as COSTnz and the Urban Planning that Sustains Waterbodies (UPSW) cost model (Ira et al., 2015) have been developed in order to further understand the long term, life cycle costs of stormwater treatment devices associated with WSD. To date, these models are showing that costs of treatment associated with a WSD approach may be more expensive than using a traditional approach to stormwater treatment. This may be due to the relatively recent nature of WSD and the lack of usable, quality cost data around WSD, but it may be also attributed to the under-utilization of WSD as an integrated part of design, which can often lead to inefficiencies due to duplication of WSD practices with conventional piped systems or a reduction in 'avoided costs' that could potentially be achieved.

This paper provides a stock take of the current understanding of the costs of WSD, and explores the issue of the cost of resilience in design. In addition, where cost data is available, the paper compares the current research to actual cost data obtained as a result of the WSD subdivision in Wanaka, Kirimoko Park. This comparison aids in refining future research efforts.

2 UNDERSTANDING AND DETERMINING COST

2.1 INTRODUCTION

A key impediment to implementation has been the perception that WSD costs more to implement both in the short term (i.e. construction and development costs), and long term (i.e. operating and maintenance costs). Cost estimation plays a key role in all development activities. For developers, the bottom-line reality of cost usually outweighs marginally increasing environmental improvements that were gained from using alternative technologies. For councils, the cost burden of long term maintenance of stormwater infrastructure is at the forefront of their minds throughout the regulatory process.

Despite the importance of cost as a tool in the decision-making process, until recently, there has been scant research undertaken in New Zealand on quantifying costs of stormwater management, and on developing consistent methodologies for determining cost. Internationally, there are three methods that are usually used to assess the economics of WSD (North Carolina State University, undated):

- Life cycle cost analysis;
- Cost comparisons; and
- Cost-benefit analysis.

The following sections discuss each of these types of cost analyses in the New Zealand context.

2.2 LIFE CYCLE ANALYSIS

A life cycle costing (LCC) approach has been suggested as an important way to estimate costs associated with stormwater devices (Taylor, 2003). The Australian/New Zealand Standard 4536 (1999) defines LCC as "the process of assessing the cost of a product over its life cycle or portion thereof". The life cycle costing process assesses the acquisition and ownership costs of an asset over its life span: from the planning and design stage, to the construction stage, to the usage and maintenance stage, and finally through to disposal.

A cradle-to-grave time frame is warranted because future costs associated with the use and ownership of an asset are often greater than the initial acquisition cost, and may vary significantly between alternative solutions (Vesely *et al.,* 2006). Life cycle costing is therefore able to describe the type, frequency and level of cost associated with a specific stormwater practice across the life span of that practice (Figure 1).

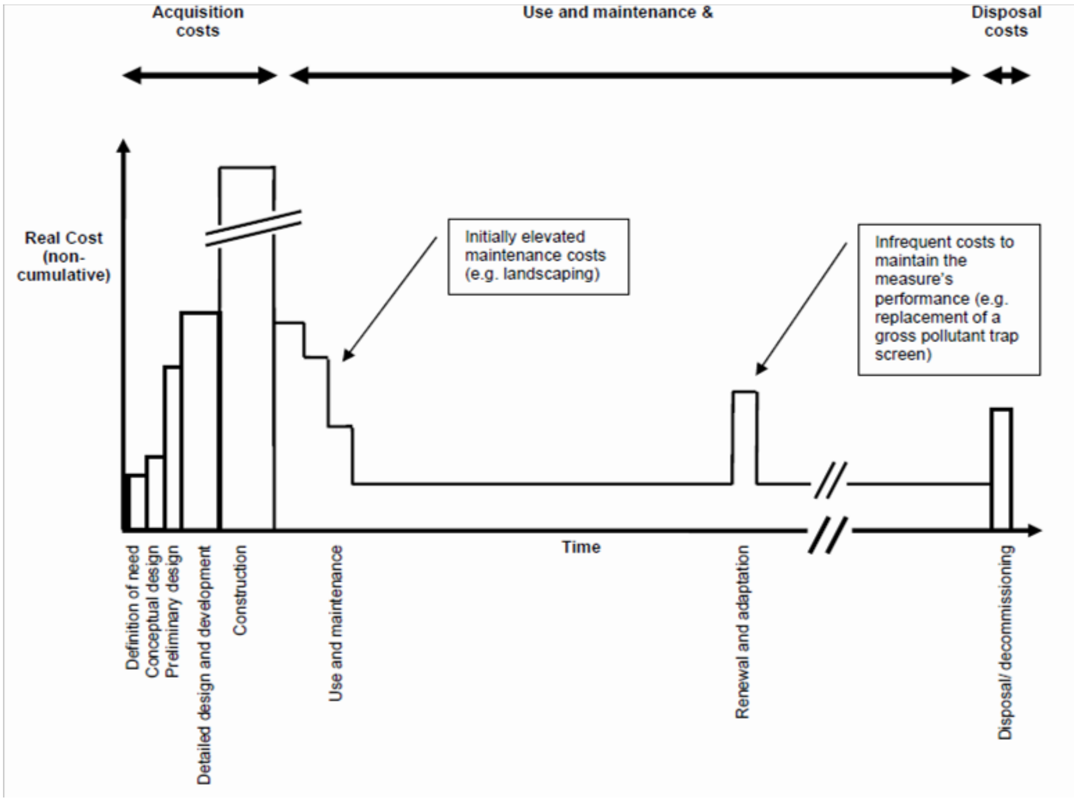
As a result, life cycle costing has a number of benefits and supports a number of applications and analyses (Lampe et al. 2005):

- it allows for an improved understanding of long-term investment requirements,
- it helps decision-makers make more cost-effective choices at the project scoping/ feasibility phase,
- it provides for an explicit assessment of long-term risk,
- it reduces uncertainties and helps local authorities determine appropriate development contributions, and
- it assists local authorities in their budgeting, reporting and auditing processes.

In New Zealand, Landcare Research has developed the COSTnz life cycle costing model to assess costs of individual stormwater treatment devices on a site specific basis. Through the UPSW programme, NIWA and the Cawthron Institute have used COSTnz to develop dollar per hectare life cycle costs for stormwater treatment on a catchment-wide basis.

This cost model was incorporated into the NIWA decision support system (DSS) model for freshwater and estuarine receiving environments. Ira *et al*., 2009, Ira 2011 and 2014 and Ira *et al*., 2015 all report on these models.

Figure 1 Phases in the life cycle of a stormwater practice and potentially associated costs (Taylor, 2003)



2.3 COST COMPARISONS

The second way of quantifying costs associated with WSD, is to undertake cost comparisons of conventional developments, and compare these with those associated with WSD developments. There have been a number of these types of studies done both here in New Zealand as well as in the United States.

Recently a literature review was undertaken (Ira, 2014) to assess the comparative case studies undertaken internationally in an attempt to quantify the cost differential between WSD and conventional developments. As reported in Ira *et al*. (2015) approximately 41 reports/ papers were sourced and reviewed (Table 1). The literature review highlighted that there is an inherent difficulty in quantifying a cost differential between WSD and traditional developments due to the high number of variables which change for each individual situation. These variables relate to amongst other things, the catchment size, impervious area to be treated, device type and the jurisdiction in which the works are located.

Table 1 Summary of cost differentials from international and national literature (Ira et al., 2015)[1]

Case Study Locality	WSUD Type	Objectives for WSD	Percentage Difference (Ave)	Cost Type
Australia	Rain tanks, rain gardens, detention basin	Water savings/ Flood storage	-55.5%	LCC
Australia	Rain tanks, rain gardens, detention basin	Water savings/ Flood storage	-27.7%	TAC
New Zealand	Rain gardens, swales, ponds/ wetlands	Treatment/ Attenuation	-13.5%	TAC
New Zealand	Rain gardens, swales, ponds/ wetlands	Treatment/ Attenuation	7 - 15xgreater	MC
New Zealand (theoretical modelling - UP)	Rain gardens, porous pavement, gravel storage	Treatment	-9.6%	TAC
New Zealand (theoretical modelling - UP)	Rain gardens, porous pavement, gravel storage	Treatment	-26.8%	MC
New Zealand (theoretical modelling - UP)	Rain gardens, porous pavement, gravel storage	Treatment	-11.0%	LCC
United Kingdom	Open storage	Reduce WW overflows	15.0%	TAC
United Kingdom	Open storage	Reduce WW overflows	-23.0%	MC
USA	Rain gardens, swales, porous paving, wetlands	Treatment, attenuation, reducing WW overflows	23.0%	TAC
USA	Rain gardens, bush trees, swales, green roof, wetlands	Treatment, attenuation, reducing WW overflows	24.0%	LCC
INTERNATIONAL AVERAGE*			**-2.6%**	**TAC**
INTERNATIONAL AVERAGE*			**-24.9%**	**MC**
INTERNATIONAL AVERAGE*			**-15.7%**	**LCC**

*Average derived from 53 case studies across 4 countries

2.4 COST BENEFIT ANALYSES

A cost-benefit analysis considers not only the full range of costs associated with undertaking life cycle costing, but also considers the economic, social, cultural and environmental benefits of a project. The analysis is more complex and time consuming than life cycle costing, but it does assist in highlighting that there are occasions where the other benefits of undertaking WSD projects can outweigh any additional expected costs.

Assessing economic benefits of WSD was been undertaken by the Cawthron Institute and NIWA, and is reported on in Ira *et al*., 2012 and 2015, and Batstone and Sinner, 2009). Whilst there is a clear need to further refine and develop cost-benefit models with respect to WSD, it is outside the scope of this paper.

2.5 SUMMARY OF COST OUTCOMES OF TRADITIONAL DEVELOPMENT VERSUS WSD

In summary, both the NZ life cycle costing models and the comparative case study literature review that has been undertaken to date has found that WSD stormwater devices generally incur greater costs over their life cycle than traditional end of pipe solutions. The following key observations have been made as a result of these literature reviews and cost model studies:

[1] TAC: Total Acquisition Costs; MC: Maintenance Costs; LCC: Life Cycle Costs

- Whilst many of the studies provided within the USA and UK show large cost savings associated with WSD, these are often compared against the cost of separating large scale combined wastewater systems.

- Many studies from the UK and USA, as well as some New Zealand theoretical case studies (ARC, 2000), show a clear saving of total acquisition costs (TAC) for WSD over traditional developments.

- The TAC saving is generally is related to the "***avoided costs***" of site earthworking, preparation, concreting and reduced piping rather than the costs of the stormwater management devices themselves. The stormwater costing models, on the other hand, only focus on the cost of the stormwater devices.

- The literature review highlighted that there is little "on-the-ground" data available regarding maintenance costs, and this should be an area of future research in New Zealand in order to further refine the existing life cycle costing models.

- Both the Auckland Council Unitary Plan Costing Report (Kettle and Kumar, 2013) and modelling undertaken for the NIWA UPSW programme demonstrated that maintenance costs of stormwater devices associated WSD are higher than traditional end of pipe costs.

- Comparative Australian case studies in the literature suggest a higher life cycle cost of WSD-type devices over traditional stormwater devices (on average 55%).

- Using the New Zealand life cycle costing models, on average, life cycle costs of WSD-type devices tend to be approximately 59% – 70% higher than end of pipe costs (NPV LCC over 50 years).

3 UNDERSTANDING AND DETERMINING THE COST OF RESILIENCE

In order for WSD to be truly sustainable, it also needs to be resilient and therefore cope with extreme weather events, natural disturbances and long term changing climatic conditions. As part of the UPSW programme to develop the DSS, NIWA is developing key indicators of resilience to use within the model. The research is presented in Moores and Semani-Davies (2015) and the paper identifies 5 types of strategy which would assist developers and councils to build resilient stormwater infrastructure. As taken from Moores and Semani Davies (2015), these include:

1. Multifunctionality (practices provide for more than one function and are intertwined or combined);

2. Redundancy and modularization (risk is spread across multiple elements);

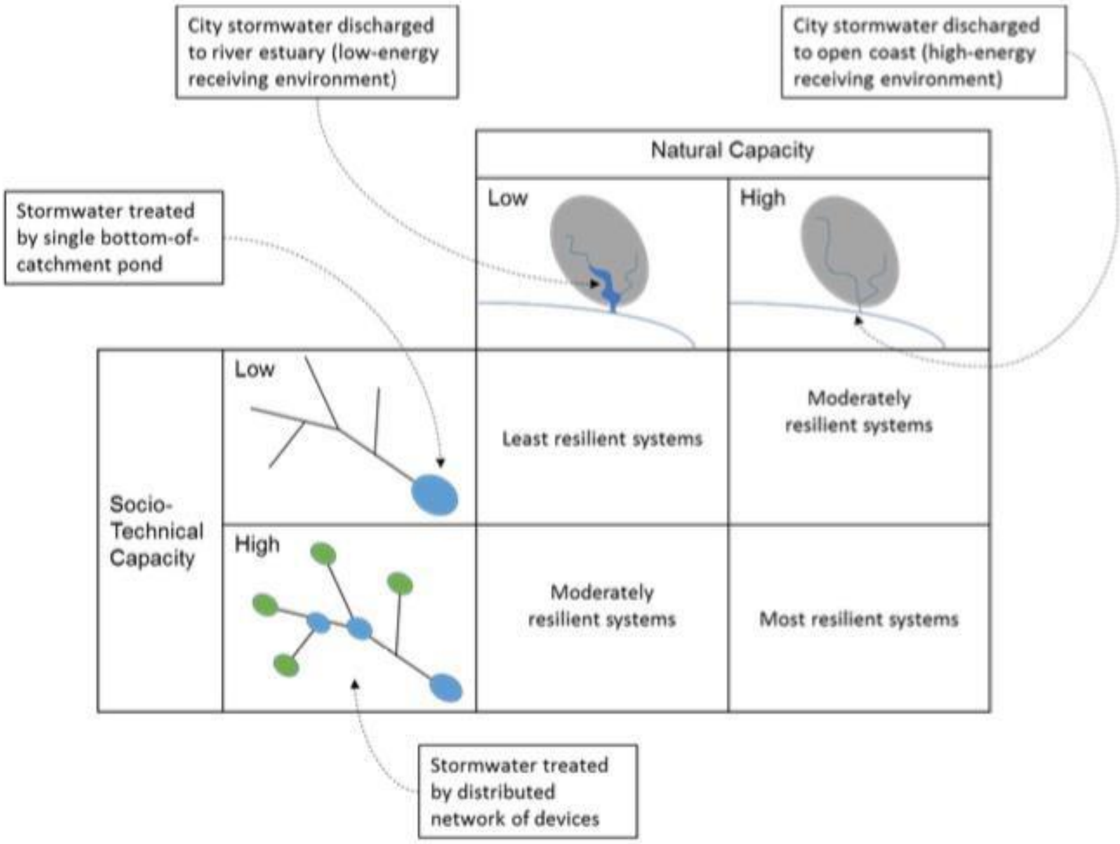
3. Bio- and social diversity is promoted (similar functions are provided by a range of elements)

4. Connectivity and multi-scale (networks are connected and linked at multiple scales); and

5. Adaptive planning allows for monitoring to inform future upgrades so that the system is continuously evolving.

These concepts are further illustrated in Figure 2, which clearly highlights that a distributed network of stormwater management devices is likely to be more resilient than a single 'bottom-of-catchment' pond. This is in-line with a WSD philosophy of source control and at source treatment.

Figure 2 Illustration of likely resilience of distributed versus 'bottom-of-catchment' treatment (Moores and Semani-Davies, 2015)



To date very little research has been undertaken in New Zealand around the likely cost of factoring 'resilience' into the stormwater design. A paper by Semani-Davies *et al*. (2013) briefly investigated this topic and the cost of adapting stormwater devices to account for climate change. The paper (Semani-Davies *et al*., 2013) reported on modelling work relating to the size and cost of ponds and rain gardens which were designed for:

- present day climatic conditions and 45% imperviousness;
- mid-century (2040) climatic conditions and 60% imperviousness; and
- end of century (2090) climatic conditions and 75% imperviousness.

The modelling work found that, for the ponds, the increase in total life cycle cost associated with adaptation is between 8.7 – 12.3%, while the increase for rain gardens is approximately 8%. The study found that the expected increase in the costs due to adaptation, are relatively minor when compared with other construction and maintenance costs. In addition, an average 10% increase in cost for adaptation is far less than construction costs of new devices to accommodate future hydraulic loads.

4 KIRIMOKO PARK – INCREASING OUR UNDERSTANDING OF WSD COST AND RESILIENCE

4.1 BACKGROUND

The Kirimoko Park subdivision was presented and discussed by Roa et al., (2015). The subdivision is located approximately 2km north of the Wanaka town centre and approximately 1km east of Lake Wanaka (see Figure 3).

Figure 3: Location of the Kirimoko Park Development in Wanaka

The site is situated above the shoreline of Lake Wanaka by a minimum of 30m, with the topography characterised by undulating gradients, gently sloping at grades of between 2 and 18% towards Lake Wanaka to the west. The localised geology of the site and surrounding environment is composed of loess and glacial till material. The New Zealand Geological Survey (NZGS) geological map indicates that the underlying stratigraphy contains outwash gravels, morainic deposits and fan talus. Soils throughout the site are dominated by sandy silts and silty sands of varying degrees of permeability. Infiltration tests undertaken prior to development concluded that infiltration rates across the site would be in the order of 50mm per hour. This conclusion was backed up through investigations on one of the constructed raingardens within Stages 1a and 1b. However, localized variation in permeability has been encountered across the site as is typical of morainic geology.

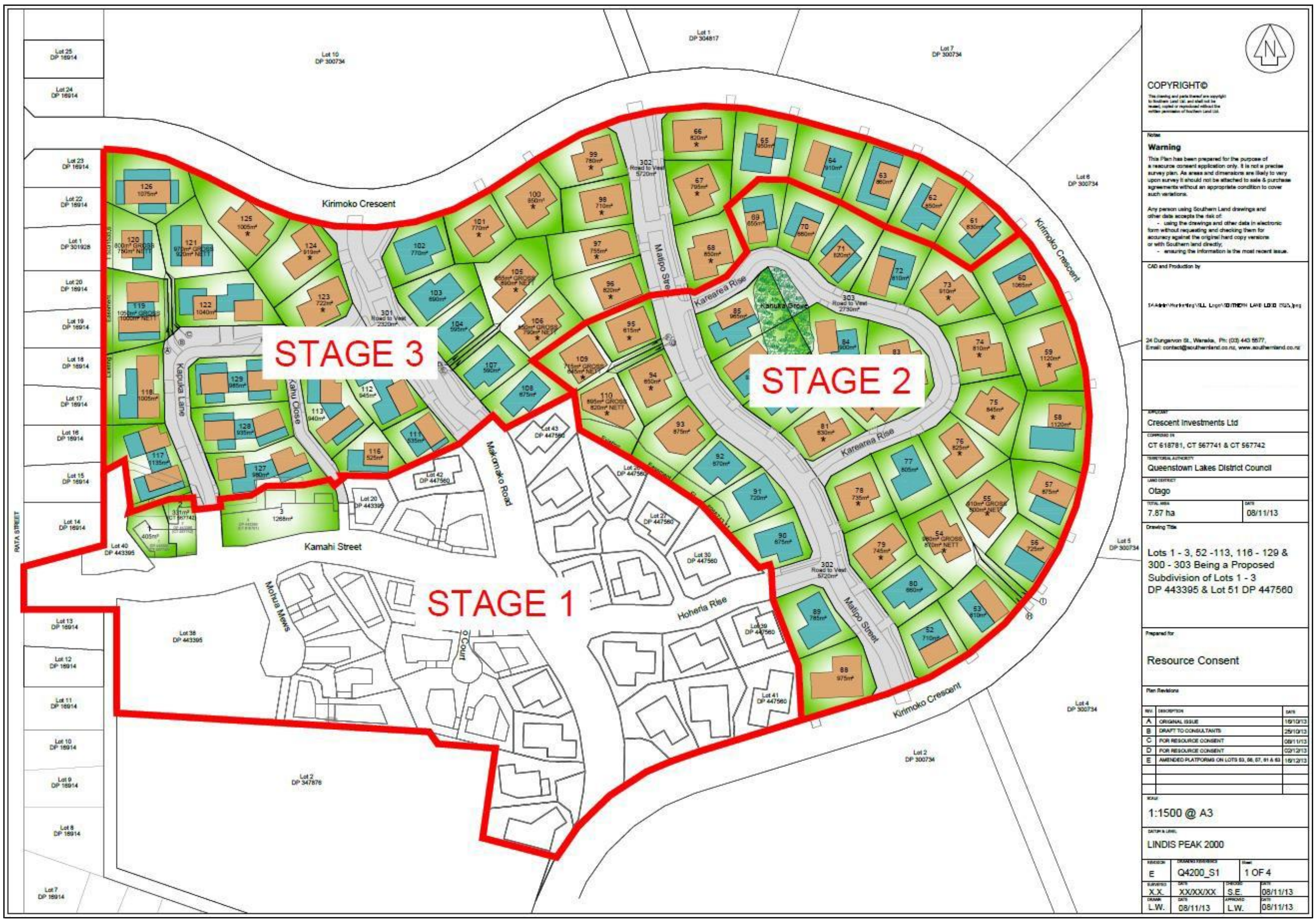
Due to the minimum 30m elevation above highest water levels within Lake Wanaka together with the comparatively coarse and permeable nature of the soils, groundwater levels have not been encountered during the development. These features are supported by existing geotechnical investigations undertaken in support of the development.

Stages 1a, 1b, and 1c of the development were completed between 2011 and 2013, and have occurred within the south west corner of the site across an area of approximately

4.15 hectares. Stage 2 was completed in 2014 / 2015 and covers an area of approximately 4.17 hectares.

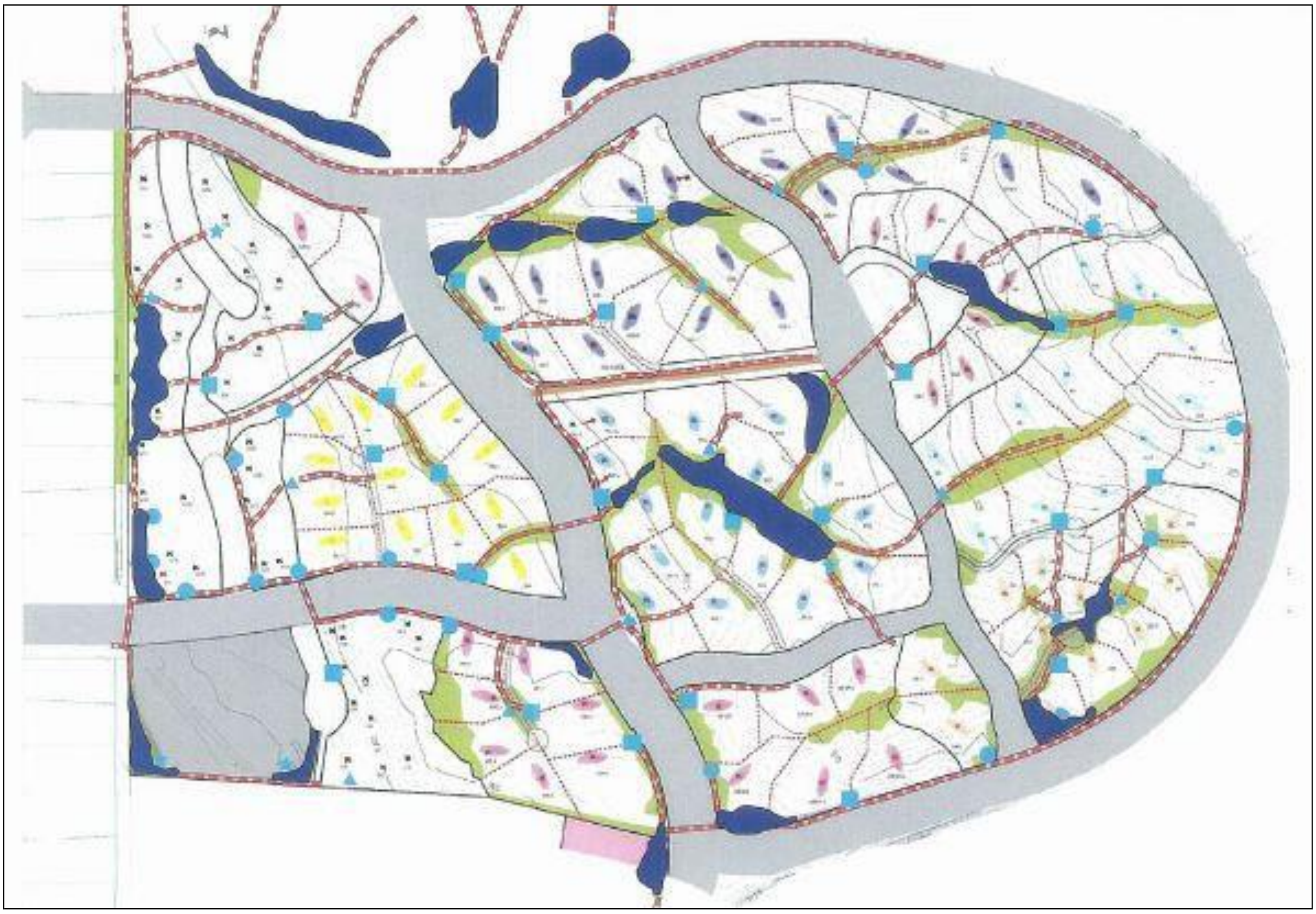
The Stage 3 and final phase of works, completed 2015 – 2016 was comprised of 38 lots and extended the same water sensitive design development philosophy north of Stages 1 and 2. See Figure 4 for the staging plan.

Figure 4: Kirimoko Park Development Showing Various Stages of Development



At Kirimoko Park, virtually all primary and secondary stormwater flows are managed on the surface, through swales, raingardens, detention / infiltration basins and fords, with very little or no piping. A stormwater management concept was developed by Pattle Delamore Partners (2009) early in the planning process, which allowed for surface water management and attenuation consistent with a WSD approach (see Figure 5).

Figure 5: Kirimoko Park WSD Concept Plan - From Pattle Delamore Partners (2009). Dark blue areas depict detention/soakage basins, red dashed lines are proposed swales and light blue symbols represent propose raingardens.



This approach has allowed WSD practices to form an integral part of the urban landscape at Kirimoko Park, where stormwater becomes an attractive resource with visible water features, showcasing stormwater as a resource rather than a burden. Importantly, as already mentioned, due to the integrated way in which the WSD and stormwater function was incorporated into the wider urban and landscape design of the subdivision, this has also translated into significant construction cost savings for the project.

The principles relating to the stormwater management aspect of the design can be summarized as follows:

- Minimisation of earthworks and maintaining existing natural drainage patterns and hydrology. This was primarily achieved by allowing the road network to follow the natural contour of the land, thereby limiting earthworks to the formation of road corridors only rather than comprehensive re-contouring of the land.

- Avoidance of pipes wherever possible.

- Encouraging the slowing of stormwater runoff, thereby promoting biofiltration and infiltration.

- Maximising the visibility of stormwater as an amenity.

- Utilisation of stormwater for the protection and enhancement of remnant and new planted areas.
- Promotion of dispersed flow patterns and avoidance of fast and concentrated discharges.
- Making use of roads, footpaths, car parking areas and other urban design elements to foster stormwater infiltration, slowdown of runoff and retention of water.
- Making use of stormwater design elements to fulfil other urban design and engineering functions, such as the use of raingardens as landscape elements or fords as traffic calming measures.
- The overall integration of stormwater design with urban architecture and landscape design.

4.2 COST

4.2.1 TOTAL ACQUISITION COSTS

The total acquisition costs (TAC) of stage 2 of Kirimoko Park was subjected to a comparative cost analysis in Roa *et al*. (2015). Unfortunately actual cost data was not reported due to the commercially sensitive nature of the cost data. However, the paper (Roa *et al*., 2015) did find that the TAC of Kirimoko Park Stage 2 was 23% more cost effective than if a traditional approach to stormwater management had been taken. Stage 3 of the development has since been completed and the WSD / conventional civil design has been compared, resulting in a 17% cost saving in favour of WSD and an average cost saving across Stages 2 and 3 of 20%. These cost savings are attributed to:

- reduced pavement costs as a result of narrower streets;
- rationalized and reduced overall roading and utility service infrastructure requirements as a result of clustering;
- significantly reduced earthwork cuts and fills as a result of maintaining the existing land form where possible and the formation of roads along contours;
- the use of swales for treatment as well as conveyance reduced the need for a costly piped infrastructure;
- additionally swales remove the need for kerb and channel, again offering savings to the project.
- the placement of WSD practices partly or wholly within private land thereby optimizing land development yield and improving landscape amenity in lots;

When the average 20% cost differential is compared with the international literature on comparative case studies, it is noted that it is similar to the studies undertaken in the USA (where WSD is 23% more cost effective), however, is inconsistent with the differential provided in Australia (-55%) and elsewhere in New Zealand (-13.5%).

A more detailed analysis of the literature, when compared with Kirimoko Park shows that:

- The majority of WSD examples within New Zealand tend to be located within Auckland, and incorporate clay soils which necessitate a piped system in conjunction with WSD-type practices in order to ensure water is kept away from steep, unstable slopes. Long Bay, NZ's most detailed WSD case study, predicted a 12% increase in TAC, on a per lot basis. It is noted that the Long Bay catchment soils are notoriously unstable and have a high clay composition.

- Many of the studies in the USA assumed that no piped network was necessary if permeable paving or infiltration practices are used – this is consistent with the approach that was taken at Kirimoko Park.

- Many of the items to which the cost reduction relates are as a result of the the WSD philosophy around site design rather than the stormwater practices themselves. Reduced impervious area, earthworking and piped costs are considered to be "avoided costs" as discussed in Section 2.5. It is noted that the New Zealand life cycle costing models, and Australian studies reviewed in the literature, focus solely on the stormwater devices themselves and do not currently take these avoided costs into account.

4.2.2 MAINTENANCE COSTS

The literature review discussed in Section 2.5 highlighted that there is little "on-the-ground" data available regarding maintenance costs. Actual maintenance cost data is notoriously difficult to obtain. Generally councils have very different database protocols and tend not to collect detailed maintenance cost data for different stormwater devices. In addition, many of the WSD-type devices have only be operating for around 10 years or so, and thus long term maintenance data is not available. When COSTnz was developed for Landcare Research in 2007, very little cost data existed and a unit costing approach to determining maintenance costs was undertaken. A further review of maintenance costs was undertaken in 2014-2015 (Ira et al., 2015). This review demonstrated that both the Auckland Council Unitary Plan Costing Report (Kettle and Kumar, 2013) and modelling undertaken for the DSS had higher maintenance costs for WSD-type stormwater devices than traditional end of pipe solutions. On average, maintenance costs of WSD devices in Australia and New Zealand incur 26.8% increased costs (another study found them to be 7 to 15 times greater than traditional costs).

Stage 2 of Kirimoko Park has now been completed for approximately 2 years. Whilst maintenance cost data is not available at the time of writing this paper, the frequency of maintenance activities was provided. Frequency is a key determining factor in understanding the long term cost of a maintenance activity. For example, some activities, such as mowing swales, would be relatively inexpensive, but would need to occur frequently throughout the year. On the other hand, clearing silt from a stormwater pond or wetland is a costly exercise, but may only need to be completed every 25 – 50 years. Table 2 compares the existing maintenance regime at Kirimoko Park against the COSTnz model information, and 2 interesting trends emerge:

1. The default maintenance frequency values within COSTnz overestimate the frequency of annual routine maintenance activities, and

2. The COSTnz swale and rain garden models do not account for increased corrective maintenance following construction. Kirimoko Park has highlighted that corrective

maintenance of stormwater devices may well be needed in the first few years following construction as the individual house lots are developed.

Obtaining information about "on-the-ground" maintenance activities is vital. It should be used to update models such as COSTnz to allow them to reflect our knowledge on what maintenance activities need to take place, how often they should occur, and how much each of those activities costs. Of these 3, obtaining actual cost data is the largest challenge, since cost information is generally commercially sensitive and not readily available in an easily comparable and consistent form.

Additionally, the correlation between maintenance cost and the extent to which WSD is implemented is also an important consideration to maintenance costs. As WSD becomes more mainstream (as in some parts of the US), competition between maintenance service providers and increased efficiencies are likely to result in maintenance costs coming down.

Table 2: Comparison of maintenance frequency between COSTnz and Kirimoko Park

Maintenance Activity	**COSTnz (default value) Frequency (per year)**	**Kirimoko Park Frequency (per year)**
Average mowing frequency for swales	6	4
Average mowing frequency for dry detention basins	N/A	4
Average trimming/ pruning for rain gardens	4	1
Average cleaning of debris and other gross pollutants for the devices	12	4
Average inspection for sediment/ weed build-up	1	2
Corrective maintenance	Varies (10 – 50 yrs)	Erosion issue in swales needed to be corrected.
Any other issues	Traffic management whilst undertaking maintenance work median or road-side swales/ rain gardens has been identified as an issue.	Work around the outlet structures from the house lots into the swales to reduce silt build-up and improve maintainability.

4.2.3 RESILIENCE AND THE COST OF RESILIENCE

Kirimoko Park has been designed with a committed focus on sustainability. This is reflected in the design of the WSD stormwater systems and roading and infrastructure at subdivision stage, and carried through to the design and construction of the individual dwellings. Table 3 below compares the Kirimoko Park design outcomes with the resilience criteria as outlined in Section 3.

Table 3: Comparison of Kirimoko Park Design Outcomes against the 5 Resilience Strategies Identified by Moores and Semani Davies (2015)

Resilience Criteria	**Kirimoko Park**
Multifunctionality	The swale network eliminates the need for kerb and channel on the road edge and are multifunctional in the sense that they provide dual functions of conveyance and treatment. The swales, rain gardens and infiltration basins assist in removal of contaminants, help to recharge groundwater and are important components of the overall urban design focus of the development. The curvilinear nature of the roads, which are designed to follow the contour, provide a passive traffic calming function resulting in improved aesthetics, amenity and urban design outcomes. Fords across roads both convey high stormwater flows and act as traffic calming devices.
Redundancy and modularization	Culverts are provided where swales intersect road corridors. The purpose of these culverts is to convey the lower, more frequent flows. When storm flows exceed the capacity of the culvert, conveyance across the road is provided by way of a ford (or saddle) in the road. The curvilinear nature of roads provides opportunity for construction of swales, as they are able to follow the curved alignment, compared with pipes which are more suited to straight road alignments. The use of swales and above-ground channels for primary conveyance purposes results in lower risks of blockage or reduced capacity when compared to pipes, translating to a more resilient and robust stormwater solution.
Bio- and social diversity is promoted	Minimizing earthworks (soil disturbance) through designing the roads along the contour where possible. Retaining the natural character of the landform and protecting existing vegetation and natural features where possible. Providing shared road spaces for low speed vehicles, cyclists and pedestrians
Connectivity and multi-scale	The swale system provides for a visible, connected stormwater conveyance network that directs stormwater flows to detention / infiltration basins. The swale network is comprised of 1st, 2nd and 3rd order swales, providing multi-scale hydrological connectivity that resembles a

	stream network form and build redundancy and multi-functionality into the system.
Adaptive planning	Kirimoko Park has been designed with a committed focus on sustainability. This is reflected in the design of the WSD stormwater systems and roading and infrastructure at subdivision stage, and carried through to the design and construction of the individual dwellings. All stormwater structures have been designed to cater for predicted future increase in rainfall due to climate change. The WSD design allows for the stormwater practices to be inspected passively as they form part of the visible landscape. This allows for early identification of any issues and continual improvements to the system. Additionally, the high aesthetic value of the WSD systems and associated landscape and streetscape also promotes a level of ownership by local residents, where they take pride in these systems, often resulting in discretionary superintendence, guardianship and care of these devices. WSD practices often also have a higher tolerance to ground movement when compared to rigid pipe systems, translating to resilience in events such as earthquakes or local ground conditions such as soil creep.

As discussed in Section 3, on average for ponds and rain gardens, a 10% increase in cost for adaptation was determined (Semani-Davies *et al*., 2013). It is considered that this 10% increase in cost is far less than what it would cost Council, or a private home owner, to construct new devices in 25 – 50 years time to accommodate future hydraulic loads.

5 CONCLUSIONS

A key impediment to implementation of WSD has been the perception that WSD costs more to implement both in the short term (i.e. construction and development costs) and long term (i.e. operating and maintenance costs). Cost estimation plays a key role in all development activities. For developers, the bottom-line reality of cost usually outweighs marginally increasing environmental improvements that were gained from using alternative technologies. For councils, the cost burden of long term maintenance of stormwater infrastructure is at the forefront of their minds throughout the regulatory process.

This paper has provided a stock-take of existing cost estimation methods which have been used to determine costs of WSD in New Zealand. Research to date shows that costing models have focused on understanding and estimating the costs associated with WSD-type devices. Separate studies have been undertaken to quantify the costs of differing approaches to site design. To date, unfortunately, there is no one model in New Zealand which brings these two important cost elements together.

Comparison of this existing research with the Kirimoko Park case study has highlighted some important findings which should act as a guide for future research. These include:

- When correctly and comprehensively implemented, WSD can lead to a cost saving of approximately 20% during the design and construction stage. This saving is consistent with studies undertaken in the USA, where WSD eliminates the need for a piped network. This is however not consistent with the cost models and case studies carried out to date in Australia and New Zealand. As mentioned in Section 4, these models and studies focus solely on costs associated with the WSD-type devices. In addition, many of the case studies are in areas where clay soils necessitate a piped system in conjunction with WSD-type practices, so there is a degree of duplication which leads to cost inefficiencies.

- Many of the items to which the cost reduction relates are as a result of the integration of WSD with the overall site design (including urban and landscape architecture), rather than just the stormwater practices themselves. Reduced impervious area, earthworking and piped costs are considered to be "avoided costs" (Section 2.5). Future costing models in New Zealand will need to take these avoided costs into account in order to ascertain the true cost of WSD when compared with traditional developments.

- Even with existing WSD case studies, maintenance cost data is difficult to collect due to the commercial sensitivity of cost information, and the relatively limited time that WSD technologies and practices have in place.

- Existing WSD case studies can provide valuable information on the type and frequency of maintenance that is currently being undertaken by contractors.

- Future New Zealand costing models need to account for increased corrective maintenance for the first 2-5 years following construction.

An analysis of the features of WSD within the Kirimoko Park case study also supports the view that a WSD approach to stormwater management is more resilient in the long term. The distributed, modularized approach of WSD assists with building multifunctionality, redundancy, diversity, connectivity and adaptive planning into the overall site design.

Although the cost of resilience has not been well researched to date, and further work is needed in this area, initial research by Semani-Davies et al. (2013) has demonstrated that costs of adaptation of ponds and rain gardens would be far less than construction costs of new devices to accommodate future hydraulic loads.

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